

Type	Final Report
Grant	NAG 5-7056
Title	Submillimeter Studies of Comets
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Period	03/01/98 - 02/28/021
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Technical Officer	Thomas Morgan
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Summary of Completed Project

This proposal supported observations of comets at submillimeter wavelengths. The prime science objectives were to use rotational transitions in molecules to measure the compositions and outgassing rates of the comets. The second science objectives focussed on the use of the submillimeter continuum radiation to provide a measure of the solid particle content and production rate in the comets. Both quantities provide fundamental constraints on the nature of these primitive bodies. The gas and dust measurements provide context for NASA's on-going and future studies of comets using in-situ spacecraft. Submillimeter continuum data, in particular, samples the largest particles in the cometary dust grain size distribution. These particles contain the bulk of the mass and present potential hazards to spacecraft when inside the dust coma.

Techniques Used

Measurements were primarily taken at the 15-m diameter James Clerk Maxwell Telescope (JCMT), with supporting data at other wavelengths from the University of Hawaii 2.2-m and Keck 10-m telescopes. We used heterodyne spectrometers with both frequency and position switching to cancel the sky background. The SCUBA bolometer array was employed for the continuum

observations.

Personnel

This grant supported research by the PI, by postdoctoral scholar Dr. Yan Fernandez, and was briefly used to secure help from University of Hawaii graduate student with data reduction. On the basis of work done under this grant, Dr. Fernandez has recently secured new support from a SIRTf Fellowship.

Findings and Implications

Under this grant we have

1 Measured the deuterium to hydrogen (D/H) ratio in comet Hale-Bopp, from both the water molecule and hydrogen cyanide (papers 2 and 4). High cometary D/H is most naturally explained by ion-molecule reactions occurring in the interstellar medium before incorporation into the comets. The cometary D/H is 3 times higher than in ocean water, showing directly that the terrestrial oceans are not formed wholly by the impact of comets like Hale-Bopp. This result has spawned a number of theoretical investigations by others which attempt to reconcile the oceanic and cometary D/H ratios with a consistent model of planetary formation and volatile accretion.

2 Measured the HNC isotopomer at a range of heliocentric distances (Paper 3). This molecule provides compelling evidence that coma chemistry occurs (i.e. the molecules and fragments in the coma interact with sunlight to yield more than just dissociation products).

3 Measured the submillimeter cross-section of Hale-Bopp as a function of wavelength, time and heliocentric distance (Paper 5). These measurements, possible only because of our special access to the JCMT, showed that

- the largest particles dominate the cometary mass balance (meaning that optical and 10 μm observations cannot be used to directly assess the mass production)
- the submillimeter spectral index of comet dust is indistinguishable from that of dust in the disks surrounding T-Tauri stars
- the perihelion production of dust in this comet was near 2000 tonnes/sec and, integrated around the orbit, some 2×10^{13} kg were released.

4 Thermal detections of macroscopic bodies (the cometary precursors ("Centaur") Chariklo, Asbolus and Chiron and the dead comets) reveal low albedos consistent with earlier measurements of the cometary nuclei, but also some objects with significantly higher reflectivities (papers 1, 8, 9 and 10). The albedos of objects with comet-like Tisserand invariants are found to be uniformly low and comet-like, providing the first evidence for a link between dynamical and physical properties. These measurements provide a hint of the richness and compositional diversity to be sampled by SIRTf.

Major Publications

- 1 D. Jewitt and P. Kalas (1998). Thermal Infrared Observations of Centaur 1997 CU26. *Astrophys. J., Lett*, **499**, L103-106.
- 2 R. Meier, T. Owen, H. Matthews, D. Jewitt, D. Bockelee-Morvan, N. Biver, J. Crovisier and D. Gautier. (1998). A Determination of the HDO/H₂O Ratio in Comet C/1995 O1 (Hale-Bopp). *Science*, **279**, 842-844.
- 3 W. Irvine, E. Bergin, J. Dickens, D. Jewitt, A. Lovell, H. Matthews, F. Schloerb, and M. Senay. (1998). Chemical Processing in the Coma as the Source of Cometary HNC. *Nature*, **393**, 547-550.
- 4 R. Meier, T. Owen, D. Jewitt, H. Matthews, M. Senay, N. Biver, D. Bockelee-Morvan, J. Crovisier and D. Gautier (1998). "Deuterium in Comet C/1995 O1 (Hale-Bopp): Detection of DCN". *Science*, **279**, 1707- 1710.
- 5 D. Jewitt and H. Matthews (1999). Particulate Mass Loss from Comet Hale-Bopp. *Astron. J.*, **117**, 1056-1062.
- 6 D. Jewitt (2000). Cometary Rotation: An Overview. *Earth, Moon and Planets*, **79**, 35 - 53.
- 7 D. Jewitt and J. Luu (2000). The Kuiper Belt. Invited review for Protostars and Planets IV. Edited by Vince Mannings, A. Boss and S. Russell, University of Arizona Press, Tucson. pp:1201-1229.

- 8 Y. Fernandez, D. Jewitt and S. Sheppard (2001). Low Albedos of Extinct Comet Nucleus Candidates. *Ap. J. Lett.*, 553, L197-200.
- 9 D. Jewitt and Y. Fernandez (2001). Physical Properties of Planet Crossing Objects. In *Collisional Processes in the Solar System*. ed. H. Rickman and M. Marov. Astrophysics and Space Science Library Series, Kluwer Academic Publishers, Dordrecht, pp. 143-161.
- 10 Y. Fernandez, D. Jewitt and S. Sheppard (2002). Thermal Properties of Centaurs Asbolus and Chiron. *Astronomical Journal*, 123, 1050-1055.